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Research on a Surface acoustic wave based PM2.5 monitor

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Abstract*— Particulate matter 2.5 is of great harm to human health. We proposed a novel $PM_{2.5}$ monitor based on surface acoustic wave (SAW), which mainly consists of a SAW dual-resonator oscillator, a thermophoresis unit, and a virtual impactor. In this paper, the FEM software COMSOL was used to simulate the heating characteristics of the micro-heater fabricated on the quartz substrate with different structures and materials, as well as the thermo-deposition distribution of particles under different hot source locations. The response of the $PM_{2.5}$ monitor was analyzed by considering the distribution of particles and the sensitivity relation of different areas on the surface of the SAW resonator. In addition, the structure of the SAW based PM2.5 monitor was optimized and designed. Finally, the micro-heater and the SAW resonator were manufactured and bonded to form the detection probe of the PM2.5 monitor, and their performances were verified by experiments.

***Keywords*—SAW, Particulate matter 2.5, micro-heater**

I. Introduction

Particulate matter 2.5 refers to particulate matter whose aerodynamic equivalent diameter in ambient air is less than 2.5μm, which is of great harm to human health because of their ability to penetrate deep into the lungs and bloodstreams, causing major health-related problems[1-2]. At present, the main working principles of PM2.5 monitors are gravimetric, β-ray decay and tapered element oscillating microbalance (TEOM) methods[3-4], and there are also some portable PM2.5 monitors, such as the light scattering method monitor[5] and the MEMS micro-fluid method monitor[6]. However, the instruments using the first three methods suffer from large volume and high price, the light scattering method monitor is of a shortage of accuracy, and the fabrication process of the MEMS micro-fluid method monitor is complex. In order to overcome the above shortcomings, a novel SAW-based PM2.5 monitor is proposed based on the characteristics of small volume and high sensitivity of SAW sensors.

The schematic of the novel SAW-based PM2.5 monitor is shown in Fig.1. Which mainly consists of a SAW dual-resonator oscillator, a thermophoresis unit, and a virtual impactor. The particulate matter is firstly separated in the virtual impactor, and then the separated PM2.5 is carried by the carrier gas into the thermophoresis unit and deposited on the surface of the SAW detector by the thermophoresis effect. The mass loading from the deposited $PM_{2.5}$ results in changes in the SAW velocity and the corresponding oscillation frequency, and accordingly, the change of the oscillation frequency is utilized for PM2.5 mass detection.

In thermophoresis unit, the hot source that provides temperature gradient field required for the PM2.5 deposition in the monitor affects the integration of the system and the sensitivity of monitor by influencing the deposition distribution of PM2.5. In order to optimize the deposition distribution of particulate matter to improve the sensitivity of the monitor, a kind of micro-heater fabricated on the quartz glass substrate based on MEMS technology is used as the hot source of the monitor. In this paper, the finite element analysis software COMSOL MULTIPHYSICS was used to simulate the heating characteristics of the micro-heater with different structures and materials, as well as the thermo-deposition distribution of particles under different hot source locations. The response of the PM2.5 monitor was analyzed by considering the distribution of particles and the sensitivity relation of different areas on the surface of the SAW resonator. According to the results of the simulation, the structure of the SAW based PM2.5 monitor was optimized and designed, including the structure and material of the micro-heater, the relative position of the SAW detector and the micro-heater, etc. Finally, the micro-heater and the SAW resonator were designed and manufactured, and they were bonded to form the detection probe of the PM2.5 monitor, and their performances were verified by experiments.

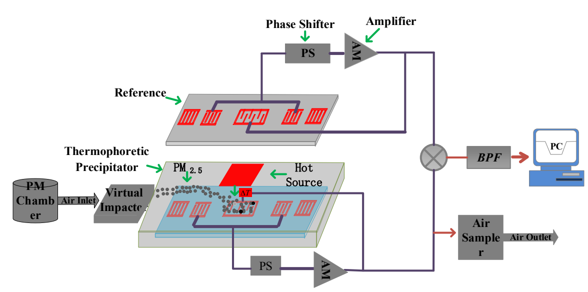


Fig.1 The schematic of the novel SAW-based PM2.5 monitor.

II. Technique Realization

A. The basic principle of the micro-heater

The hot source that provides temperature gradient field required for the PM2.5 deposition in the monitor affects the integration of the system and the sensitivity of monitor by influencing the deposition distribution of PM2.5. In order to optimize the deposition distribution of particulate matter to improve the sensitivity of the monitor, a kind of micro-heater fabricated on the quartz glass substrate based on MEMS technology is adopted as the hot source of the monitor. The

MEMS micro-heater is a kind of film heater made on the upper shell of the micro-channel. Its basic structure includes a heating thin-film resistance acting as a hot source and a temperature measuring thin-film resistance acting as a temperature sensor. The working principle of micro-heater is shown in Fig.2.

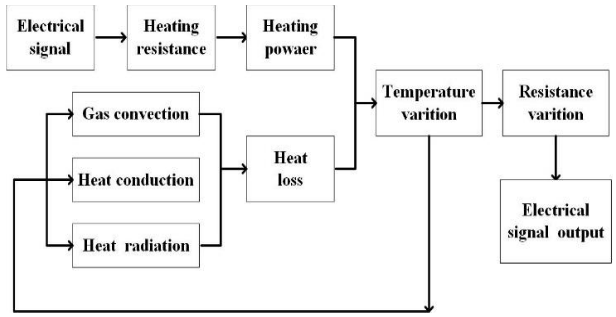


Fig.2 The working principle of micro-heater

When the electrical signal is inputted and the current flows through the heating thin-film resistance, the joule heat generated by the resistance heats up the micro-heater to the predetermined operating temperature. The value of the film resistance changes due to temperature change. The heating thin-film resistance is designed with annular structure to achieve the uniform temperature distribution, and the layout of the micro-heater is shown in Fig.3.

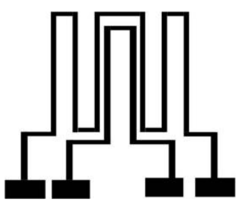
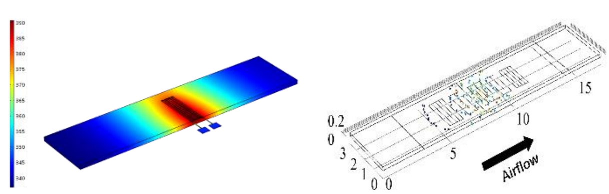


Fig.3 The layout of Micro-heater

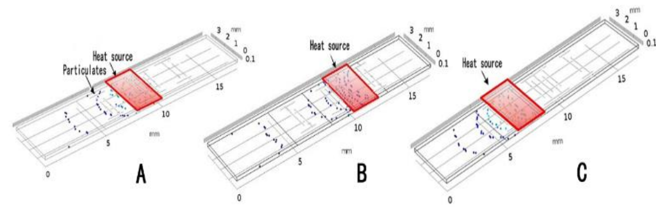
B. *The theoretical analysis*

The finite element analysis software COMSOL MULTIPHYSICS was used to simulate the heating characteristics of the micro-heater with different structures and materials, as well as the thermo-deposition distribution of particles under different hot source locations. Fig.4 shows the temperature distribution of the heater and the corresponding deposition distribution of PM2.5. Then the responses of SAW monitor with different heat source positions and different particle distribution conditions were analyzed, as shown in fig.5, the particulate matters are mainly distributed in the middle region of SAW resonator when the heat source is in position A, which can achieve good sensitivity[7]. Finally, the optimal parameters of the structure, material and position of the micro-heater were obtained according to the simulation results.

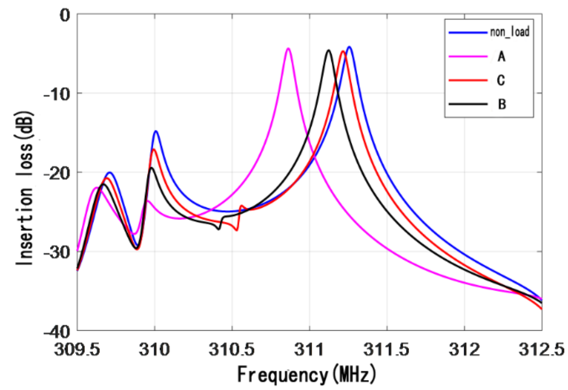


(a) (b)

Fig .4 COMSOL simulation:(a)Temperature distribution of Micro-heater (b)The thermo-deposition distribution of particles when the micro-heater is located above the intermediate IDT.



（a）



（b）

Fig.5 (a) Deposition distribution of particles at different heat source positions and (b) frequency response of SAW sensors to the particles under corresponding conditions.

III. EXPERIMENT AND RESULTS

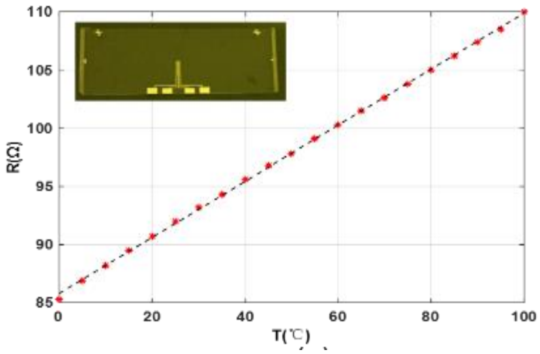
The micro-heater and the SAW resonator were manufactured and bonded to form the detection probe of the PM2.5 monitor. Then their performances were tested by experiments.

A. *The micro-heater*

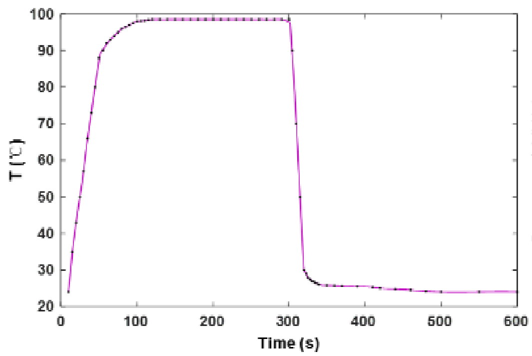
The MEMS technology (coating, lithography, corrosion and so on) were used to fabricated the micro-heater, in order to control the steady heating of micro-heater and realize the accurate measurement of temperature by temperature sensor, the performance of micro-heater and temperature sensor should be measured. Using the Altium Designer, a PCB was designed to bind the micro-heater. To verify the performance of the micro-heater, the TCR (temperature coefficient of resistance) calibration test and the heating and cooling experiments were carried out, as shown in Fig.6.

B. *The experiment results*

The experimental system is shown in the Fig.7. SAW based PM2.5 monitors with heat source structure of micro-heater and semiconductor refrigerant were used to detect cigarette particulate matter. The concentration of cigarette particles detected by the monitors of the two structures was the same during the test. The curve in Fig.8 are the frequency responses of the two SAW monitors to the cigarette particles. The red dash curve represents the response of the monitor with the micro heater and blue dash curve represents which of the monitor with the pellet semiconductor refrigerant.



(a) The relationship between resistance and temperature



(b) The heating and cooling curve of the micro-heater

Fig.6 the performances of micro-heater

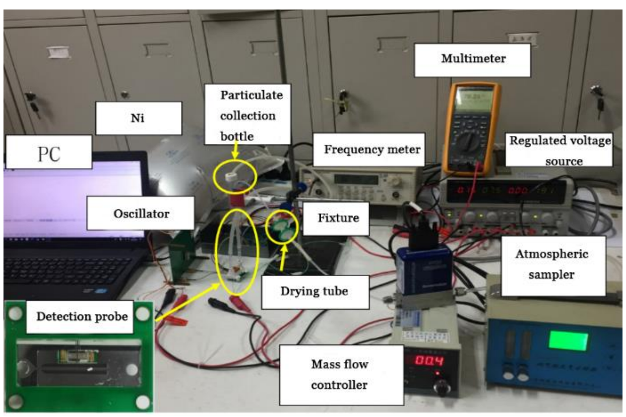


Fig.7 The experimental system

The experiment results show that the heat source structure of SAW based PM2.5 monitor was optimized by using MEMS technology instead of pellet semiconductor refrigerant. The response of the monitor was twice as high as that of the semiconductor chilling plate hot source when detecting the particulate matter of the same concentration of cigarette.

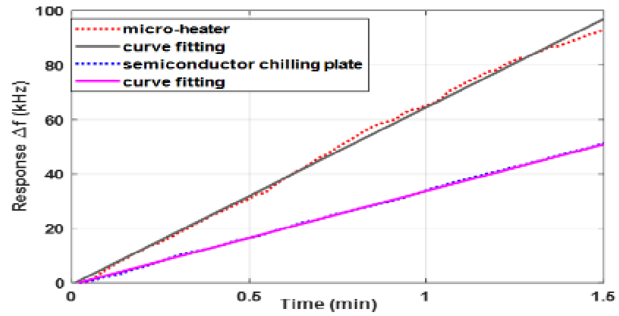


Fig.8 The test results of cigarette particulate

IV. CONCLUSIONS

The resistance temperature calibration result of the micro-heater showed that there was a good linear relationship between the heating temperature and the resistance value, and the fabricated micro-heater had a rapid rising and cooling speed. Using the cigarette particles as the sample, the performance of SAW based PM2.5 monitor was tested. The experimental results showed that the response of the monitor with the micro heater was twice as high as that of the one with the semiconductor chilling plate hot source when detecting the particulate matter of the same concentration of cigarette.

ACKNOWLEDGMENT

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